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14-MeV Neutron Generator Used as a Thermal Neutron Source

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Abstract: One of the most important applications of the general purpose Monte Carlo N-Particle (MCNP5 and MCNPX)) codes is neutron shielding design. We employed this method to simulate the shield of a 14-MeV neutron generator used as a thermal neutron source providing an external thermal neutron beam for testing large area neutron detectors developed for diffraction studies in biology and also useful for national security applications.

Nuclear reactors have been the main sources of neutrons used for scientific applications. In the past decade, however, a large number of reactors have been shut down, and the importance of other, smaller devices capable of providing neutrons for research has increased. At Brookhaven National Laboratory a moderated Am-Be neutron source with shielding is used for neutron detector testing. This source is relatively weak, but provides a constant flux of neutrons, even when not in use. The use of a 14 MeV energized neutron generator, with an order of magnitude higher neutron flux has been considered to replace the Am-Be source, but the higher fast neutron yield requires a more careful design of moderator and shielding. In the present paper we describe a proposed shielding configuration based on Monte Carlo calculations, and provide calculated neutron flux and dose distributions.

We simulated the neutron flux distribution of our existing Am-Be source surrounded by a paraffin thermalizer cylinder (radius of 17.8 cm), 0.8 mm cadmium, and borated polyethylene as biological shield. The thermal neutrons are available through a large opening through the polyethylene and cadmium. The geometrical model for the MCNP5[1] and MCNPX[2] simulations is shown in Fig. 1.

We simulated the Am-Be source neutron energy distribution[3] as a point source having an energy distribution of four discrete lines at 3.0 (37%), 5.0 (35%), 8.0 (20%) and 11.0 (8%) MeV energies. The estimated source strength based on the original specifications is $6.6 \cdot 10^6$ neutrons/sec. The simulation accurately predicts the measured thermal neutron flux at the collimator (Figure 2), thus providing validation for this method. Using MCNPX we simulated the neutron and photon dose distribution and also obtained a good agreement with the measured values.

Having established a validated framework for the shield calculation we then scaled up the Am-Be arrangement to simulate the shielding required for the higher neutron energy and flux of the neutron generator ($\sim 10^8$ neutron/sec at 14 MeV). Given the physical dimensions of the generator we have chosen a cylindrical geometry, where the generator tube is placed vertically into a cylindrical thermalizer (25 cm paraffin) from above. The thermalizer is surrounded by 0.8 mm cadmium, and a cylindrical borated polyethylene shield. A cylindrical opening (radius of 7.6 cm) serves to direct the neutrons out towards the experimental area (on the right side). The initial model is shown in figure 3.

The first goal of the calculations was to establish the minimal required radius of the biological shield. For this purpose we performed MCNPX neutron and photon dose distribution calculations by tallying the absorbed dose on a 200x200 cm mesh in the vertical center plane superimposed over the geometry. Figure 4. displays the neutron dose distribution along the central horizontal (X) axis. As observed from the figure, a shielding radius of ~80 cm is sufficient to obtain a dose level of $< \sim 4$ mrem/hour outside the shield (except from the open neutron channel on the right).

In the next step we studied the optimization of the thickness of the paraffin thermalizer by increasing the depth of the neutron exit channel into the paraffin cylinder. It was found, that the thermal flux greatly increases if we have thinner paraffin layer, an optimal value being about 5 cm thickness. But as a drawback the flux of fast neutrons also increased. A thicker thermalizer layer, in fact, acts as shielding. A slightly off centered, tangential placement of the neutron channel provides a solution which maximizes the thermal flux to fast neutron yield. Figure 5. and 6. display the final results, where we included an outside biological shield (20 cm thickness) providing a shielded experimental area. There is a 10-100 n/cm^{2}sec flux near the neutron beam exit, and outside the shield the neutron dose is below the radiation area limit (~5 mrem/hour).

References:

1. MCNP5 User's Manual, LANL Report, LA-CP-03-0245, 2003
2. MCNPX User's Manual, LANL Report, LA-CP-07-1473, 2008
3. J. E. Lutkin, G. W. McBeth, Nucl. Instr. Meth. 107 (1973) 165-171.

FIGURES

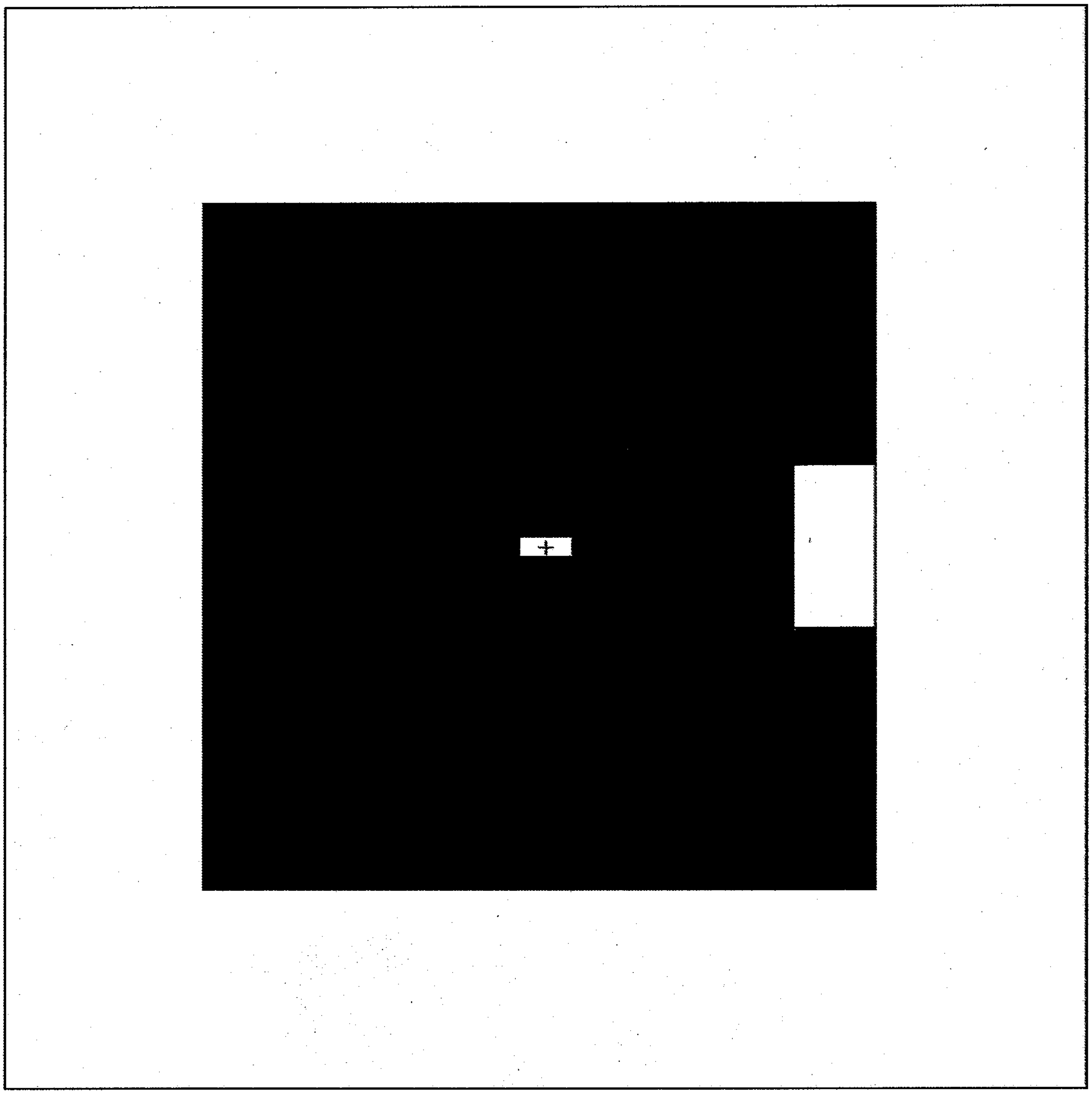

Fig. 1. Geometrical model for the Am-Be calculation. Purple: paraffin thermalizer, blue: cadmium, green: borated polyethylene, yellow: air. The Am-Be source is at the center. The cylindrical setup is shown in the vertical cross section, where it appears to be rectangular. The thin cadmium shielding is barely visible.

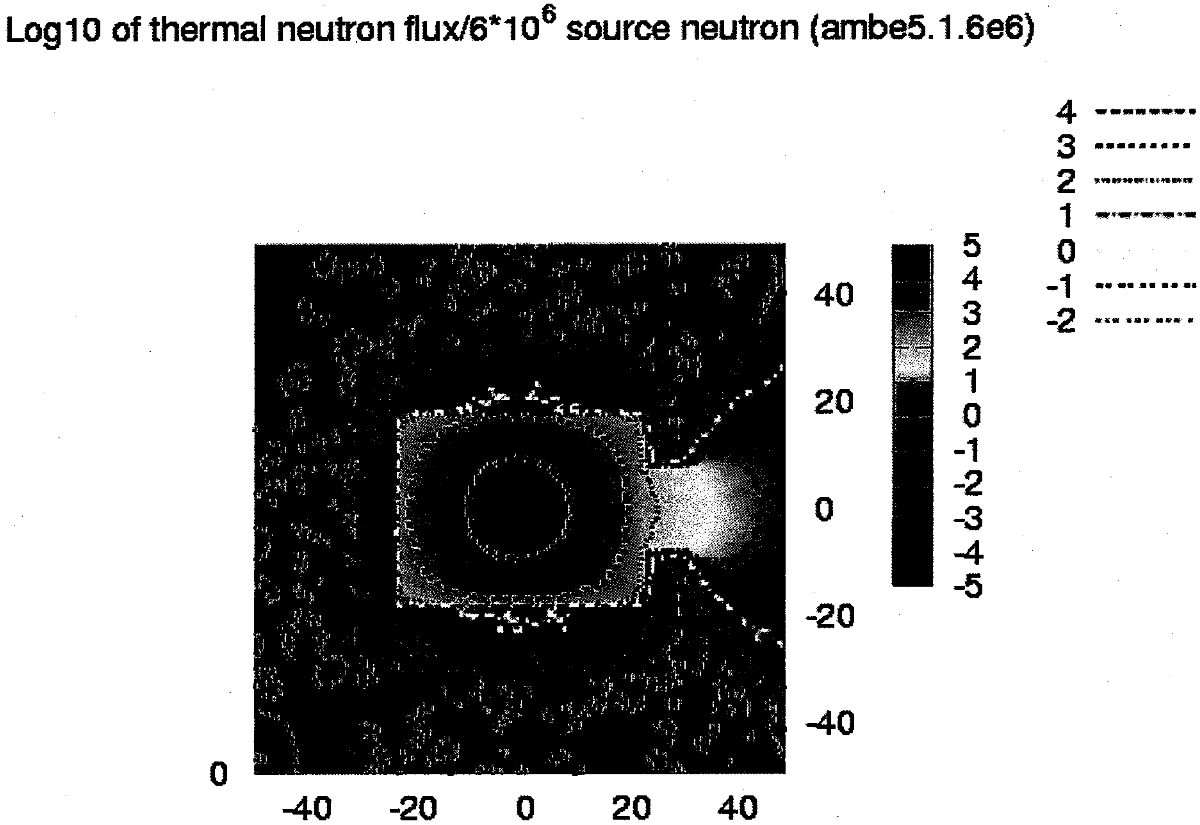

Fig. 2. MCNP5 mesh tally (in the central vertical plane, dimensions are in cm) of the logarithmical thermal flux distribution for $6.6x10^6$ source neutrons. The calculated flux at the collimator is in good agreement with the measured values.

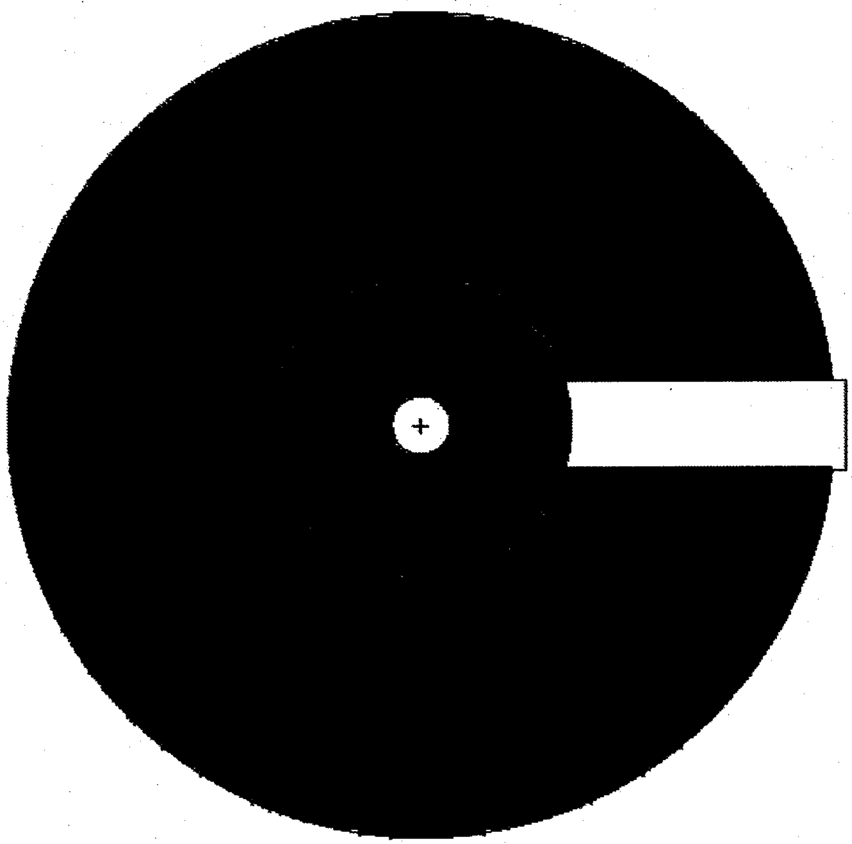

Fig. 3. Geometrical model (top view) for the 14-MeV calculations. Purple: paraffin thermalizer, blue: cadmium, green: borated polyethylene, yellow: air. The neutron generator target located at the center of the picture.

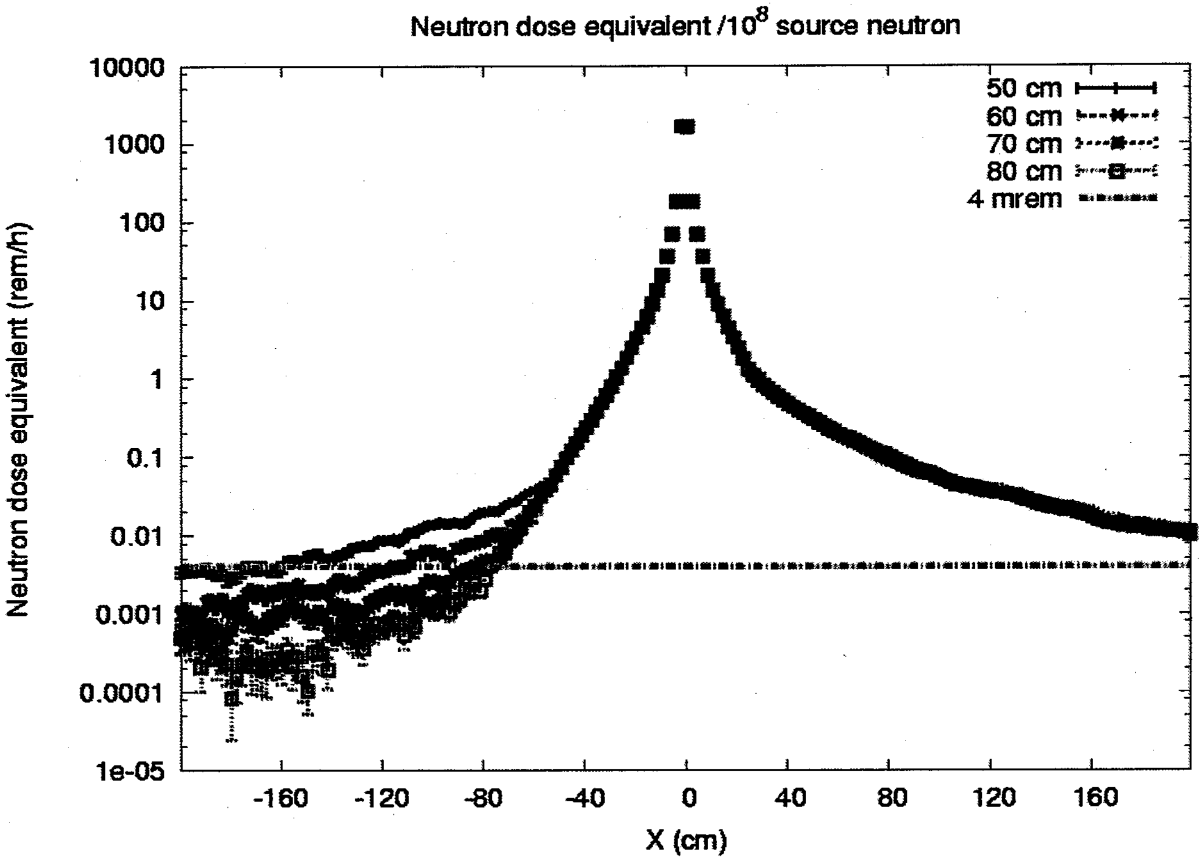

Fig. 4. Neutron dose equivalent (in rem/h) as a function of shielding radius. At about ~80 cm radius the dose falls below ~4 mrem outside the shield.

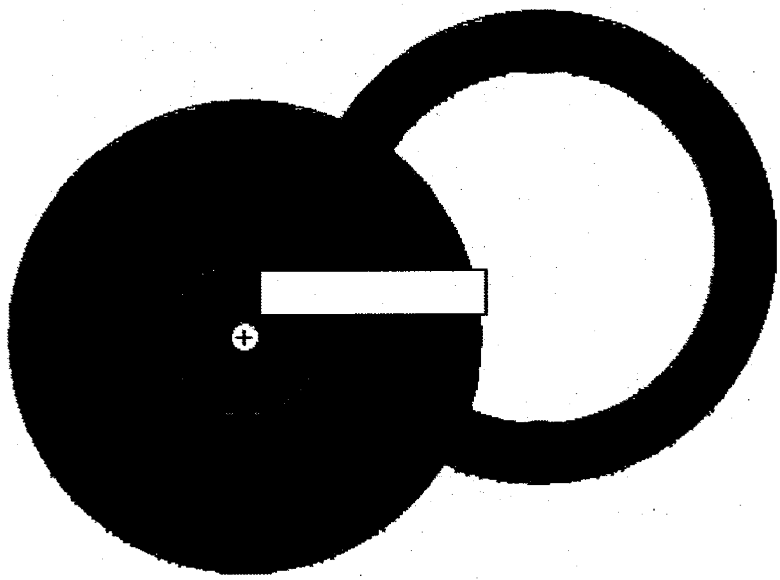

Fig. 5. The final model, including a shielded experimental area.

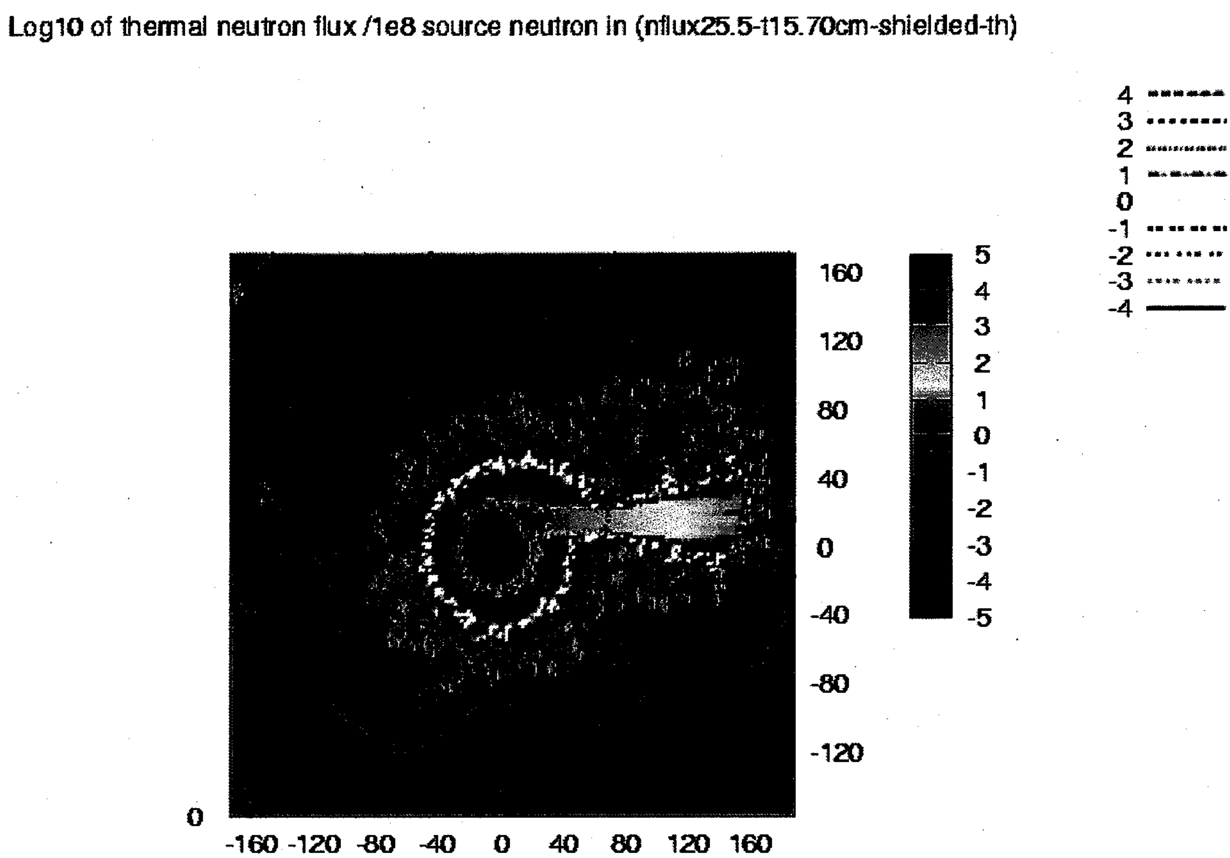

Fig. 6. Logarithmic thermal neutron flux distribution corresponding to the final model calculation.